IAA-L-0505

LOW COST APPROACH TO MARS PATHFINDER AND SMALL LANDERS[1]

Anthony J. Spear
Mars Pathfinder Project Manager
Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive, M/S 230-235
Pasadena, California 91109-8099

Abstract

NASA's Mars Surveyor Program will launch small orbiters to Mars, each carrying subsets of the Mars Observer instruments, starting as early as '96, to achieve the Mars Observer Mission objectives. Small landers will follow, as early as '98, accomplishing surface investigations as determined by the NASA AO process.

Mars Pathfinder, launching in December '96 and landing July 4,'97, will demo a low cost delivery system to the surface of Mars for follow-on Mars Surveyor and Discovery Program landers. Historically, spacecraft that orbit or land on a distant body carry a large amount of fuel for braking at the planet. Pathfinder requires fuel only to navigate to Mars, and then aerobrakes into the Mars atmosphere, deploys a parachute at 10 km above the surface and, within 100 m off the surface, fires solid rockets for final braking prior to deployment of air bags which cushion touchdown. After landing, petals open to upright the lander.

The major objective of Pathfinder, acquisition and return of engineering data on EDL and lander performance, will be completed within the first few hours after landing. In addition, the lander will transmit panoramic images of the Martian surface the first day. Next, a rover will be deployed, as early as the first day, to perform mobility tests, image its surroundings including the lander, and place the APX against a rock to make elemental composition measurements.

The primary mission durations for the rover and lander are one week and one month, respectively. However, there is nothing to preclude their operations past the primary mission durations, and both are expected to operate longer.

While Pathfinder is an engineering demo, it accomplishes a focused, exciting set of science investigations with a stereo, multi-color lander imager; atmospheric instrumentation, used as a weather station after landing; the APX; and the rover including its aft and forward cameras.

This paper features Pathfinder's approach to innovative and cost effective project implementation, capped at 150 Mil $ (FY '92) for development plus 22 Mil $ (FY '92) for the rover. Pathfinder is pathfinding a new way of doing business at NASA and JPL for small, low cost, Discovery class missions.

In addition, this paper will summarize the approach to small lander missions after Pathfinder, in particular the importance of Pathfinder to these missions.

APX = Alpha Proton X-Ray Spectrometer   EDL = Entry, Descent, Landing

1 = The work described in this paper was performed at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration

MARS PATHFINDER IMPLEMENTATION STRATEGY

Pathfinder is in a special "cheaper, better, faster" project operating mode, accomplishing a challenging mission at low cost and fixed price, using a "Kelly Johnson" like skunkworks approach, focusing on a limited set of objectives, and streamlining project approaches and minimizing bureaucratic interference. NASA's Office of Space Science is developing Pathfinder. The Advanced Concepts and Technology Office teamed with the Space Science office is developing the Pathfinder rover. Pathfinder is being performed at JPL in its in-house, subsystem mode.

To land on Mars with a rover at low cost, the Pathfinder project:

- Acquired institutional support priority within JPL, in particular, in quick formation of a motivated, projectized, collocated "skunkworks" team
- Achieved Up-Front Agreements with JPL and NASA management, which are documented in the Pathfinder Project Plan and must be maintained
- Acquired support in key EDL technologies from Sandia National Laboratory and NASA's Langley and Ames Research Centers
- Leveraged NASA's investment in JPL's planetary mission infrastructure, making cost effective use of mission design tools, navigation techniques, multi-mission GDS and MOS capabilities, and the JPL Flight System Test Bed
- Balanced use of available and new technology, each application weighed carefully as to its contribution to low cost and risk
- Supported NASA in streamlining the lander camera AO process which led to selection of a powerful camera utilizing the Cassini Huygens Probe CCD and its associated electronics
- Practiced concurrent engineering from the outset among mission, navigation, flight system, instruments, rover, ground data system, ops, product assurance, procurement
- Developed a centralized system architecture around a single flight computer for cruise, EDL, surface ops
- Accomplished early proof of concept testing for EDL and the rover
- Is performing early interface/functional testing in the JPL Test Bed among the flight system, instruments, rover, flight S/W, GDS, MOS sequences
- Will assembly quickly and test thoroughly. ATLO begins 18 months before launch

Pathfinder was funded sufficiently in its 19 month pre-project phase to perform the necessary trades for selection of an EDL approach; to accomplish significant design of the flight system, including rover and instruments, as well as the GDS and MOS; and to accomplish detailed planning and cost estimating. Pathfinder interacted with available sources of Mars lander expertise to arrive at its EDL approach in an August '92 peer review including industry, other NASA and government centers, and other countries such as Russia. Its design, implementation and cost estimates were formally reviewed twice in the pre-project phase by a Standing Review Board -- the July '93 review being its System PDR and NAR equivalent.

At project start in October '93, the project had a significant segment of the GDS up and running, had performed an Earth-Lander-Rover uplink/downlink data test and was ready with long lead procurement documents. Three months after project start, an Integrated Project Schedule and a cost update were completed. The Integrated Project schedule details all key steps necessary across all project elements to be ready for launch on December 5,'96, including both Pasadena and ETR ATLO. The cost update reflected changes in the plan due to the loss of Mars Observer spares.

EDL = Entry, Descent, Landing	GDS = Ground Data System	S/W = Software
MOS = Mission Operating System	PDR = Preliminary Design Review	NAR = Nov-Advocate Review
ATLO = Assembly, Test, Launch Operations	CCD = Charged Coupled Device	ETR = Eastern Test Range

The baseline Pathfinder development scope is costed at 131 Mil $, and we currently hold 40 Mil $ reserves, adding to 171 Mil real year $, equivalent to the 150 Mil $ (FY '92) cap. Exploiting the JPL existing multimission institutional infrastructure has permitted acquisition of the GDS and MOS for 12 Mil $, a substantial reduction to that which has been spent historically at JPL. " The total allocation for science and instruments is 15 Mil $. The APX, developed for the Soviet Mars '94 mission, costs 1.0 Mil $ plus another 1.0 Mil $ for the APX deployment mechanism. The lander camera is being furnished by the PI, cost capped at 5.0 Mil $. Project management is costing 5 Mil $. The largest use of funding at 99 Mil $ is directed at flight system development.

The rover is being developed for 25 Mil $ real year, on top of the 171 Mil $ allocation.

Because Pathfinder is pushing to do more for less under a relatively low cost cap and shorter schedule, the following development priority list, keyed to mission success criteria, will guide the use of reserves and descope decisions, if necessary, to stay within the cost cap:

PATHFINDER DEVELOPMENT PRIORITIES

1. Delivery System to Mars: cruise and EDL
2. Cruise and EDL telemetry instrumentation for realtime and stored telemetry transmission
   a. cruise, cruise separation and EDL critical event telemetry
   b. g levels in atmosphere and on landing
   c. aeroshell temperature/pressure measurements
3. Transmission of stored EDL and realtime lander engineering telemetry as soon as possible after landing

- 50% mission success -

4. Transmission of a subset of the panoramic image

- 70% mission success -

5. Deployment of the Rover and support of Rover engineering operations

-9070 mission success -

6. Transmission of APX data with APX deployed against rock and soil by Rover
7. Transmission of camera science data acquired in daytime, dawn to dusk, for 7 days
8. Transmission of camera science data acquired in nighttime for 7 days
9. Transmission of stored atmospheric science (accelerometer, pressure, temperature) data after landing
10. Transmission of surface measurements of temperature and pressure for 30 days
11. Transmission of camera science data acquired in daytime, dawn to dusk, for 30 days
12, Transmission of camera science data in nighttime for 30 days

-10070 mission success --

The most important feature of Pathfinder's approach is collocation of all key team members on the same floor of one building around the JPL Test Bed. Collocation simplifies lines of communication and facilities rapid iteration of requirements, and resolution of issues and problems. Team members from the JPL technical divisions remain administratively tied to their home division, in what is called the "soft projectized mode", but are responsible to the project for performance, cost and schedule of their work packages, not to the divisions. We are self-contained, including product assurance and procurement teams collocated with the project.

GDS = Ground Data System
MOS = Mission Operations System
EDL = Entry, Descent, Landing
PI = Principal Investigator
APX = Alpha Proton X-Ray Spectrometer

Our Project Engineering Team (PET), with membership from all project elements, is our major concurrent engineering vehicle. PET coordinated Project document development including the Project Plan and lower level requirements stemming from the Project Plan's Level 1 requirements. PET is responsible for tracking compliance to requirements, for planning incremental H/W and S/W deliveries to the JPL Test Bed for early phased testing, as capabilities evolve, and for coordinating the Engineering Configuration Control and Problem/Failure processes. PET also acts as the project referee in working "PET PEEVES: problems that impact requirements or have an impact to other elements of the project. The early phased tests in the JPL Test Bed essentially gives us a head start on ATLO with early interface and functional testing in parallel with developments, prior to the formal start of ATLO in June '95.

The Pathfinder Flight System is a blend of available and new technology, each application is carefully weighed as to its contribution to performance, risk and cost.

Pathfinder uses the following available equipment or designs:

- Cassini
- Magellan Star Scanner
- Adcol Sun Sensors
- Viking heritage aeroshell and parachute designs
- DOD developed RAD rockets and altimeter

All flight equipment is being subjected to rigorous inheritance review and to space qualification testing tailored to the Pathfinder mission regardless of previous testing history.

Pathfinder's key new technology uses include:

- A free ranging rover with on-board autonomous navigation
- A solid state X-Band power amplifier
- A RAD hardened IBM RS 6000, 32 bit flight computer
- Air bags adapted for use in Mars atmosphere
- Lander image data compression

The rover, X-Band *power* amplifier and EDL, in particular the air bags represent the major Pathfinder developments, and significant work was accomplished on each of these in the pre-project phase including proof of concept air bag tests at Sandia, rover mobility tests and breadboard power amplifier development at JPL.

The EDL system is comprised of subsystems with heritage requiring little or no development (air bags is the exception), the challenge lies with incorporating these into an effective, space qualified system. While EDL system demonstration and qualification testing are of major importance, they are not on the critical path relative to ATLO and can be accomplished largely independently, in parallel with ATLO. ATLO critical path items include the lander structure, harness, power subsystem, AIM which embodies the central computer, the flight S/W and the rover,

Pathfinder's major challenge is:

- Accomplish both the Pathfinder and rover developments within their cost caps: 171 and 25 Mil $, real year, respectively

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H/W = Hardware　　S/W = Software　　ATLO = Assembly, Test, Launch, Operations
EDL = Entry, Descent, Landing　　DOD = Department of Defense
RAD = Rocket Assisted Deceleration　　AIM = Attitude Information System

Accomplishing development in 3 years is a lesser challenge, especially with the quick start made possible by the pre-project phase. We have planned ATLO at one shift per day, 5 days per week in Pasadena, and 6 days per week at ETR. We hold 22 weeks of schedule margin distributed in ATLO, in addition to extra shifts and weekends which are bookkept as a lien on reserves.

Except in FY '93 where there are two, Pathfinder conducts one formal review each year before a Standing Review Board with the System CDR in September '94, the next review. An ATLO Readiness Review conducted in May '95 and a pre-ship, MOS Readiness Review conducted in August '96 are the remaining formal reviews before launch. In May '97, a Surface Ops Readiness Review will be conducted.

Mars is most Earth-like of the terrestrial planets and may have supported life. It has stirred interest and imagination for many decades and will continue to be the target for human exploration in the next century. A no less important objective is communication to the public of Pathfinder's exciting robotic exploration of Mars, including student interaction with the mission through Pathfinder's Education Outreach program. In addition, Pathfinder's Technology Transfer Plan identifies technologies with commercial spin-off potential.

MARS PATHFINDER MISSION DESCRIPTION

A single Mars Pathfinder flight system will be launched to Mars in the period December 4, 1996 to January 3, 1997 from a Delta II, landing on July 4, 1997. The flight system is spin stabilized during cruise, spinning at 2 rpm, with the spin axis and medium gain antenna pointed to earth except for the first 20 days after launch, when the spin axis is pointed closer to the sun line. After the first 20 days, the sun line remains within 40 degrees of Earth, and the earth point attitude is maintained until Mars atmosphere entry, including cruise trajectory maneuvers which are performed in the vector mode: thrusting along or perpendicular to the spin axis. All cruise critical events are telemetered in real time to earth.

Twenty four hours before Mars arrival, the flight system will turn approximately 5 deg. to its entry attitude and, keeping in touch with Earth, will jettison its cruise stage and enter directly into the Mars atmosphere, braking with an aeroshell, parachute, small solid retrorockets and air bags.

The entry velocity is 7.6 km/sec (17,100 mph) compared with Viking at 4.6 km/sec which entered from orbit. Mars Pathfinder's entry angle is 16.7 deg. (90 deg. would be straight down) and peak atmospheric shock, 25 g's, is encountered at 32 km above the surface. The parachute is deployed at Mach 1.8 (900 mph) at 10 km, 100 seconds after atmospheric entry. Ames Research Center, supporting Mars Pathfinder's aeroshell design, has arc-jet tested the Viking SLA 561 ablative material planned for use on Mars Pathfinder, to insure it can withstand the extra heat pulse due to the larger entry velocity.

Langley Research Center is accomplishing the aerodynamic analysis for entry and descent and is supporting design of the parachute, a Viking derivative disk-gap-band design with an 11 m diameter. Early proof of concept air bag tests were accomplished at Sandia in the spring of '92 and follow up tests are planned in the summer of '94. Sandia is also consulting on the parachute design.

EDL engineering telemetry will be transmitted to Earth in real time to the extent possible. Before chute deployment, earth remains near the spin axis behind the craft and communication to earth is through a low gain antenna at 40 bps. After chute deployment, the Earth moves to approximately 90 deg. from the spin axis including chute swing, making communications more difficult. At this time, we are striving to maintain the telemetry rate at least at 10 bps, but may need to fall back on maintaining carrier

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ATLO = Assembly, Test, Launch Operations
CDR = Critical Design Review
EDL = Entry, Descent, Landing
ETR = Eastern Test Range
MOS = Mission Operations System

presence detection only.[2] EDL, lasting for 5 minutes, will be supported with the 70 m arrayed with available 34 m antennas. On the surface, the vehicle will right itself by deploying petals which expose solar panels to the Sun for powering surface operations.

After landing, the lander will transmit stored EDL data and real time lander and rover engineering telemetry first. Panoramic images of the surface will be also transmitted to Earth the first day. The rover will be deployed as early, as the first day, for start of its surface operations. The rover conducts surface mobility experiments, images rocks and soil and deploys the APX on soil and against rocks. While 30 day and 7 day primary surface missions are planned for the lander and rover, respectively, close to 100% of all lander and rover engineering and science objectives are achieved nominally in the first few days of surface operations. Currently, no constraint precludes operations of the lander or the rover past their primary mission requirements.

The Pathfinder scientific payload includes instrumentation for measuring atmospheric and landing deceleration; pressure and temperature during entry and while on the surface; a 12 spectral channel, stereo lander camera for surface and atmospheric imaging, including imaging magnetic properties targets, a wind sock and support of rover navigation; and the rover-deployed APX for elemental composition measurements of rocks and soil. The rover carries aft and forward cameras for demonstrating autonomous hazard avoidance and imaging its local surroundings, soil and rocks, and the lander.

MARS PATHFINDER KEY MILESTONES

Project Start	October 1, 1993
System CDR	September 1994
ATLORR	May 1995
ATLO Start	June 1995
Pre-Ship, Launch RR	August 1996
Launch period	Dec. 5, 1996- Jan. 3, 1997
Surface OPS RR	May 1997
Landing on Mars	July 4, 1997
Complete 30 day surface mission	August 1997
End of Mission	August 1988
End of Project	September 1998

MARS PATHFINDER KEY TECHNICAL CHARACTERISTICS

(1) A low cost, EDL system capable of:
a. storage in space during cruise
b. entering directly and descending through the Martian atmosphere from a Type 1 approach trajectory, launched in the 1996 opportunity
c. accommodating an upper wind induced horizontal velocity of 20 m/see at impact
d. impacting on rocks up to 0.5 m in diameter
e placing the lander on the surface at less than 50 g's landing shock
f. uprighting the lander

2 = the carrier maybe amplitude modulated at this time to communicate critical events only such as aeroshell, and chute deployments, RAD firing and air bag deployment

EDL = Entry, Descent, Landing
APX= Alpha, Proton, X-ray Spectrometer
CDR = Critical Design Review
ATLO = Assembly, Test, Launch Operations
RR= Readiness Review

(2) A low cost, centralized system architecture built around a RAD hardened IBM RS 6000 computer for cruise to Mars, EDL, surface operations, capable of:
a. providing for power, propulsion, telecommunication and attitude control during cruise to Mars
b. providing for sequencing, pyro firing, and telecommunications control in EDL
c, providing for power and telecommunications control in lander operations
d. processing engineering, rover and instrument data for transmission
e. support of rover surface operations
f. providing flight system fault management and safing during cruise, EDL and lander surface operations
g. operating in the cruise, EDL and Mars surface environments

(3) A low cost, multi-color, stereo lander camera capable of:
a. providing a panoramic image of the Martian surface
b. supporting rover navigation
c. acquiring surface and atmospheric science data
d. storage in cruise, surviving EDL, operations in the Mars surface environment

(4) A low cost rover capable of:
a. self-powered, autonomous surface operations in the Mars surface environment
b. communicating to lander over a UHF link
c. placing APX against rock and soil
d. storage in cruise, surviving EDL, operating in the Mars surface environment

MARS PATHFINDER MAJOR CONTRIBUTIONS TO FUTURE LANDERS

The combination of Pathfinder's development and operations experience base with that acquired by Viking will provide an extensive, demonstrated set of capabilities for future Mars landers.

In 1976, two Viking landers were carried into orbit by orbiters. After aerobraking with an aeroshell and parachute, final deceleration was performed with rocket deceleration against Mars gravity, with active 3-axis attitude control, using a liquid propellant system. Both horizontal and vertical velocities were near zero at touchdown, and the landers landed on legs. The main telemetry path to earth was via a relay link through the orbiters, however the Viking landers also had a direct link backup. Viking lander access to soil was through an arm, and these landers were powered by RTG's.

Mars Pathfinder's flight system is self contained, will cruise to Mars on its own, directly enter the Martian atmospheres without orbiting Mars, aerobrake with a Viking derivative aeroshell and parachute, but land semi hard at up to 20 m/s horizonal and up to 20 m/s vertical velocities. Landing will be limited to <50 g's using an air bag system designed to accommodate 1/2 m size rocks. The lander tumbles and rolls across the surface and rights itself using petals much like an opening flower, Pathfinder's telemetry link with earth is direct and access to both soil and rock is with the rover. Pathfinder's lander and the rover are solar powered.

RAD = Rocket Assisted Deceleration — EDL = Entry, Descent, Landing
APX = Alpha Proton X-ray Spectrometer — UHF = Ultra High Frequency
3 = An entry concept pioneered by Ames in their Mars studies

Future landers may be launched to Mars as early as '98 in the Mars Surveyor or Discovery Programs. Some of these landers will be close derivatives or smaller versions of Pathfinder. In addition, Hughes and Rockwell are accomplishing further study of small lander architectures in '94 in support of the Mars Surveyor Lander Program. One Discovery proposal under study is planning to land a Pathfinder near duplicate vehicle near the North Pole of Mars. Other landers will repackage Pathfinder's centralized system architecture using emerging micro electronics and lighter materials to reduce size and volume. 'This will have a ripple effect in reducing end to end mission cost, in particular in enabling launches of landers from smaller launch vehicles. These smaller landers will have a focused science investigation objective, around one or a few measurements, determined by the NASA AO process.

Mars Pathfinder Major Contributions to future landers are designs, developments, lessons learned, in particular:

- A low cost, fast track project implementation approach
  - Pushing to do more for less under a cost cap
- A low cost, robust, passive entry, descent, landing system scalable to a wide range of missions
  - Aeroshell, parachute, RAD, air bags, uprighting petals can be individually or wholly used by follow-on missions
- A self-contained flight system architecture built around a state of the art, powerful central computer for Cruise, EDL, Surface Operations
  - Can fly to Mars on its own
  - Can communicate directly with earth
  - Future landers will repackage this architecture with emerging micro-electronics, and advanced, lighter materials to reduce mass and volume
- A powerful stereo, multi-color surface imager
- A free ranging, autonomous navigating rover with instrument placement capability
- Solar powered lander and rover

RAD = Rocket Assisted Deceleration　　　EDL = Entry, Descent, Landing

MARS PATHFINDER FACT SHEET

- LAUNCH VEHICLE: DELTA-II 7925. LAUNCH PERIOD: Dec. 5'96- Jan. 3'97
- LAUNCH MASS: 654 kg (CBE) MARGIN: 240/o
- LAUNCH VEHICLE FIGURE OF MERIT: 40 m/s (mean magnitude of TCM #1)
- TYPE 1 TRAJECTORY, ARRIVAL: July 4'97
- TRAJECTORY CORRECTION MANEUVERS (TCM) IN VECTOR MODE[1] :

Trajectory Corection Maneuver Schedule (TCM) in Vector Mode

Maneuver	Time (days)	Expected Magnitude (m/s)	99% Mag (reds)
TCM #1	Launch + 30	40.0	92.0
TCM #2	Launch +60	2.9	8.0
TCM #3	Arrival -60	0.3	0.8
TCM #4	Arrival -10	0.1	0.3

- CRUISE PROPELLANT: 100 kg
- CRUISE TELEMETRY RATE: 40 bps, 34 M, X-Band at Mars (1.3 AU, 191 x 10^6 km)
- CRUISE COMMAND RATE: 125,250 bps, 34 M, X-Band at Mars
- CRUISE NAV DATA TYPES: two-way, X-Band Doppler, Ranging
- DSN CRUISE TRACKING COVERAGE: Continuous coverage launch to launch+ 30 days and Mars arrival -45 days to Mars arrival; 3 x 8 hour passes per week in between
- CRUISE ATTITUDE CONTROL: Star scanner, sun sensors, 2 rpm spin, medium gain antenna along spin axis pointing to Earth; Sun within 400 of spin axis after 1st 20 days after launch. No turn from Earth during cruise. During 20 days after launch, spin axis 20° off Earth.
- AIMING PLANE TARGET SIZE: 130 km x 45 km (3 sigma)
- LANDING SITE UNCERTAINTY 200 km x 100 km (3 sigma)
- EDL APPROACH : Aeroshell, Parachute, RAD, Airbags, Uprighting petals
- TURN TO ENTRY: 24 hours from entry
- EDL SEQUENCE:

Event	Velocity[2]	Altitude	g-Level	Time to Land
• Cruise Stage Sep	7.6 km/see	10,000 km		35 min
• Peak Atmospheric Shock	4.8 km/see	30 km	25	170 sec
• Chute Deploy[3]	420 m/sec	9.4 km		111 sec
• Heatshield Release	152 m/sec	8.3 km		101 sec
• Bridle Deploy	71 m/see	6.6 km		75 sec
• Rad Fire	50 m/see	90 m		1.5 sec
• Impact	O to 20 m/see	Om	50	O sec

1 = Thrusting perpendicular to and in parallel with spin axis
2 = Relative to Mars
3 = Chute Deploy at Mach 1.8. Chute Terminal Velocity: 50 m/sec
4 = Carrier amplitude modulated to signal key EDL events

CBE = Current Best Estimate
RAD = Rocket Assisted Deceleration

- ATMOSPHERE ENTRY ANGLE: -16.7 Deg.
- EDL MASS: 400 kg (CBE), MARGIN: 16% (relative to β = 50), Ballistic coefficient (13) 45 kg/m^2 (CBE)
- DSN EDL COVERAGE: 70 M arrayed with 34 M's
- EDL TELEMETRY RATES: 40 bps, prior to chute deployment; X-Band, 10 bps to carrier only[4] after chute deploy.
- EDL COMMAND RATES: No commanding during EDL
- LANDER MASS: 250 kg

- NOMINAL SURFACE OPS SEQUENCE:

Event	Sol	LST hh:mm	date	GMT hh:mm	Time after landing hrs	Time after landing min
Land	1	3:14	7/4/97	01:15	0	0
Airbag retraction	1	3:59	7/4/97	02:01	0	46
1st Earth rise, 20° mask	1	4:13	714197	02:15	1	0
Petal Opening (possible carrier link)	1	4:44	7/4/97	02:47	1	32
Establish comm with Earth, elev=55°, LGA at 40 b/s	1	6:53	7/4/97	05:00	3	45
1st Sunrise, 20° mask	1	7:08	7/4/97	05:15	4	0
Complete downlink EDL telemetry	1	7:53	7/4/97	06:01	4	46
Establish 1st **common** HGA, data rate=1260 b/s	1	8:47	7/4/97	06:57	5	42
Complete downlink panorama portion for rover deploy	1	10:23	7/4/97	08:35	7	20
Establish accurate common HGA, data rate=5530 b/s	1	12:37	7/4/97	10:53	9	38
Complete downlink IMP pre-deploy panorama	1	13:28	7/4/97	11:45	10	30
Deploy Rover	1	13:29	7/4/97	11:46	10	31
Rover image of lander	1	13:44	7/4/97	12:02.	10	47
Rover image of soil	1	13:56	7/4/97	12:14	10	59
APX on soil	1	14:03	7/4/97	12:21	11	6
Complete downlink rover image of soil	1	14:03	7/4/97	12:21	11	6
1st Earth set, 20° mask	1	14:11	7/4/97	12:30	11	15
1st Sunset, 20° mask	1	16:51	7/4/97	15:14	13	59
Rover image of rock	2	11:28	7/5/97	10:22	33	7
Complete downlink rover image of rock	2	11:44	7/5/97	10:38	33	23
Complete downlink IMP post-deploy planning panorama	2	12:40	7/5/97	11:36	34	21
Complete downlink rover image of lander	2	12:42	7/5/97	11:38	34	23
Complete downlink APX soil data	2	12:43	7/5/97	11:39	34	24
APX on rock	3	10:20	7/6/97	09:51	56	36
Complete downlink APX rock data	4	7:26	7/7197	07:32	78	17
Complete rover technology experiments (finish rock APX)	4	7:26	7/7/97	07:32	78	17
Complete lander primary mission objective (end of sol 4 downlink)	4	14:11	7/7/97	14:28	85	13

- Surface operation telemetry rates, high gain antenna, X-Band: 6 kbps } 70 m antenna
- Surface operation telemetry rates, low gain antenna, X-Band: 40 bps }
- Surface operation command rates, high gain antenna, X-Band: 125,250 bps
- Surface operation command rate, low gain antenna, X-Band: 7 bps

SOL = Mars Day
LST = Local Standard Time
IMP = Imager Mars Pathfinder (lander camera)

- ROVER CHARACTERISTICS
  - Total mass: 16kg
    + Mobile mass: 11.5 kg (including APX deployment mechanism APX instrument
    + Lander Mounted Rover Equipment Mass: 4,5 kg (includes UHF modem, support structure)
  - On board, autonomous navigation using laser striping
  - 6 Wheel, rocker bogie mobility system
  - UHF command and telemetry links with lander
  - Carries aft and fore cameras, APX deployment mechanism, APX
  - Solar panel, primary battery
  - 3 RHU's for thermal control

- LANDER COMPUTER CHARACTERISTICS
  - Cruise attitude control/maneuvers; EDL control; command and telemetry processing and control; science data processing and control; lander image compression
  - RAD 6000 (formally IBM, now Loral), 32 bit, 20 MIPS capability, 3.3 watts (5,0 MIPS nominal), 2 M byte EEPROM, 128 M bytes DRAM mass memory, computer with DRAM 0.9 kg, EE prom 0.7 kg
  - RAD hardened version of IBM commercial RS 6000
  - VME backplane • VX works operating system

- MARS PATHFINDER MASS (CBE):
  - LAUNCH MASS 654 kg
    - Dry cruise stage 154 kg
      - Structure, solar panels, propulsion stage, medium gain antenna
    - Cruise propellant 100 kg
  - ENTRY MASS: 400 kg
    - Aeroshell 90 kg
      - Diameter 2.65 m, Viking SLA 561 ablator material
    - Parachute 22 kg
      - Diameter 11.5 m, Viking heritage disk gap band design
    - RAD 24 kg
    - Opening/Uprighting mechanism 53 kg
    - Lander Structure 123 kg
    - Lander Electronics 65 kg
    - Lander Instruments (AIX, camera) 7 kg
    - Rover 16 kg

MARS PATHFINDER - VIKING COMPARISON

Item	Mars Pathfinder	Viking
• Launch	Dec. '96	VL-1 8/20/75 VL-2 9/9175
• Trajectory type	Type I	Type II
• Cruise period	7 months	Approx. 1 year
• Arrival period	7/4/97	VL-1 7/20/76 VL-2 9/3/76
• Entry, descent, landing approach	Direct from cruise flight, Aeroshell, chute, airbags RAD, uprighting petals	From orbit Aeroshell, chute Rocketbrake active guidance, legs
• Site latitude, longitude	10-20° north, undecided longitude	VL1 : 22.0° N, 47.5° W VL 2: 47° N, 225.5° W
• Site targeting accuracy	200 km x 100 km (3 sigma)	VL 1:30 km (actual) VL 2: 10 km (actual)
• Arrival conditions	Land at night Approx. 10 hrs. of sunlight available Approx 11 hrs. of earth view available	
• Lander launch mass kg (excluding adapter)	800 kg	1070 kg*
• Lander mass	250 kg	600 kg
• Entry velocity	7.65 km/s	4.6 km/s
• Entry angle	-16.7°	-12.8°
• Comm approach	Direct link	Relay link Direct link backup
• Power source	Solar panels, battery	RTG's
• Data rate	5 kbps (70 M antenna)	1 kbps
• Surface life	30 days, 1 year goal	More than 3 years
• Redundancy	Single string	Full

EDL = Entry, Descent, Landing
RAD = Rocket Assisted Deceleration
APX = Alpha Proton X-ray Spectrometer
CBE = Current Best Estimate
MGA = Medium Gain Antenna
' = Viking landers carried to Mars by orbiters - No cruise functions